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# HIGH-ENERGY $\bar{p}p$ AND pp DIFFERENTIAL CROSS SECTIONS AND RESIDUE FUNCTIONS FROM REGGE POLES*

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## ABSTRACT

A P, P' and $\omega$ Regge pole model that accounts for experimental pp and $\bar{p}p$ differential cross sections and pp polarization is proposed. The complete spin structure of the amplitude is used. A set of residue functions is determined.

At the present experimental high energies (6 to 25 GeV/c), the slopes of the $\bar{p}p$ and $pp$ differential cross sections, $d\sigma/dt$, are very different, about 15 and 6.6 respectively.[1] In addition, they intersect at an invariant moment transfer, $t$, of about $-0.2(\mathrm{GeV})^2$. A simple theoretical interpretation has been masked by complications such as the spin structure of the amplitudes and the lack of knowledge of the relevant residue functions.

Similarly for $pn$ and $\bar{p}n$ charge-exchange scattering, it has been found experimentally that the $pn$ slope is larger than the $\bar{p}n$ slope. In this case also a crossover point has been predicted.[2] On the basis of the Regge pole theory, we propose a model of the residue functions which accounts for the difference of slopes and crossover.

The five amplitudes, $\Phi_i$, that determine $NN$ scattering can be written in terms of the pole trajectory contributions in the form

$$\Phi_i = \sum_{L=1}^{N} \zeta_L \phi_{iL} , \tag{1}$$

where $L$ is the index that designates the trajectory, $\zeta_L$ the signature factor, and $\phi_{iL}$ the part that includes kinematical and isospin factors. In turn, $\phi_{iL}$ can be expressed in terms of the amplitudes of the crossed channel, $f_{jL}(t)$, by

$$\phi_{iL} = \sum_j K_{ij}(s,t) f_{jL}(t) \tag{2}$$

where $K_{ij}(s,t)$ is the element of the transformation, and $s$ and $t$

the invariant energy and momentum transfer, respectively. In the processes of interest, the transition amplitudes, $f_{jL}(t)$, are associated with the known pole trajectories, P, P', and ω. For these poles, the amplitudes become[3]

$$
\begin{aligned}
f_{1L} &= 0 \\
f_{2L} &\approx g_{11}(L,t)\left(\frac{2s}{4m^2 - t} - 1\right)^{\alpha(L,t)} \\
f_{3L} &\approx g_{22}(L,t)\left(\frac{2s}{4m^2 - t} - 1\right)^{\alpha(L,t)-2} \qquad (3) \\
f_{4L} &\approx g_{22}(L,t)\left(\frac{2s}{4m^2 - t} - 1\right)^{\alpha(L,t)-1} \\
f_{5L} &\approx g_{12}(L,t)\left(\frac{2s}{4m^2 - t} - 1\right)^{\alpha(L,t)-1} ,
\end{aligned}
$$

where $g_{11}(L,t)$, $g_{22}(L,t)$, and $g_{12}(L,t)$ are the residue functions, and $\alpha(L,t)$ the trajectory.

With various contributing trajectories, the problem of finding the residue functions is very complicated, because of the freedom provided by the several unknown residues. When experiment is confronted with theory, a reconciliation must be found between this freedom and physical constraints, such as unitarity, spin structure, the factorization theorem, and the assumption of real analyticity of the residues. This problem is expected to become simpler only at much higher energies.[4] Here we have included the contributions of P, P', and $\omega$ only, since they are the most important for the pp and $\bar{p}p$ processes. In this form we have avoided unnecessary complications that may obscure the clarity of the conclusions.

We have considered momentum transfers in the interval $-1.0\ (\mathrm{GeV})^2 < t < 0$, to remain within the domain of the Regge model. We have taken trajectories that pass through known intercepts.[5] In most of the calculations we have used straight-line trajectories to facilitate the interpretation of the results. The five helicity amplitudes were calculated without resorting to approximations.

For straight-line trajectories, the following features are consistent with the pp and $\bar{p}p$ differential cross sections and the pp polarization data. (a) The slope of P may be taken in the interval $0.25 \lesssim \alpha'(P,0) \lesssim 0.4$. The best fits correspond to a slope of about 0.3, a fact that is in agreement with a recent $\pi N$ determination.[6] (b) The slope of P' is found to be high, $1.3 \lesssim \alpha'(P',0) \lesssim 1.5$. (c) The slope of $\omega$ is found to be within the range $0.7 \lesssim \alpha'(\omega,0) \lesssim 1.0$, with the best fits corresponding to a slope of about 0.7.

We found that to account for the difference of slopes and the crossover, it was necessary to assume that $g_{11}(\omega,t)$ decreases rapidly for $t < 0$ and that it becomes negative at $t \approx -0.12(\text{GeV})^2$. Earlier work demonstrated a similar conclusion,[7] although then there was some doubt since the complete spin structure had not be considered. Some of the implications of the vanishing of this residue have already been discussed.[8] Similarly in pn and $\bar{p}n$ charge-exchange, a similar behavior was found for the residue of the odd signature trajectory, $g_{11}(\rho,t)$.[2]

Trajectories of the form $\alpha(P,t) = 1.0 + 0.3t$, $\alpha(P',t) = 0.7 + 1.4t$, and $\alpha(\omega,t) = 0.5 + 0.7t$ have been assumed in the calculation of the residue functions shown in Figs. 1 and 2. The characteristics of the model here presented are the following: (a) The residue $g_{11}(t)$ of the poles of even signature remains on the positive side of the plane. First, $g_{11}(t)$ decreases to zero for the momentum transfer for which the corresponding trajectory crosses the axis $J = 0$, then rises again. In the region considered, this is the case at least for P', for if we put as a condition that the slope of $g_{11}(P',t)$ must remain positive, then it is not possible to obtain a reasonable $\chi^2$, unless one allows the P' trajectory to have a negative slope in the region $t < 0$. This latter alternative seems less reasonable.[9] (b) On the other hand, the residue $g_{11}(\omega,t)$ of the pole of odd signature crosses the axis $g_{11}(\omega,t) = 0$ and remains on the negative side of the plane. This general trend is required to maintain the difference of slopes. A behavior similar to (a) and (b) was found respectively for R and $\rho$.[2] (c) In an ideal version of this model, with no contributions neglected, the $g_{11}(t)$ residues should become tangent to the axis at momentum transfers corresponding to the passing of a trajectory for a physical J value. (d) The solutions found satisfy the condition of real analyticity of the residues with good approximation, since for each pole L, $g_{22}(L,t)$ is found to become negligible near the point where $g_{11}(L,t)$ vanishes. That is, for the t region in which $g_{11}(L,t) > 0$, this condition is satisfied exactly and for the region in which $g_{11}(L,t) \leq 0$, only approximately, since then, $g_{22}(L,t) \approx 0$, and $g_{12}(L,t) \approx 0$. (e) The factorization theorem, e.g.,

$$g_{11}(L,t)g_{22}(L,t) = [g_{12}(L,t)]^2 , \tag{4}$$

has been used to calculate the $g_{12}(L,t)$ residue function, which on account of (d) is important mainly in the region in which $g_{11}(L,t) > 0$ .

For easier interpretation of the results, we have limited our calculations to the three most important trajectories. Nevertheless, we have fitted low energy data such as polarizations. To compensate for the trajectories neglected, the $g_{22}(P',t)$ residue becomes unrealistically high. This in turn is compensated for by the slight fictitious intrusion of $g_{11}(P',t)$ in the negative part of the plane and by the high value assumed for the slope of the P' trajectory.

In conclusion, the NN residue functions here determined are in agreement with existing experimental total cross sections, differential cross sections, and polarizations. They are related by factorization constraints to many scattering amplitudes, such as those of $\pi$N and KN ,[8] and might be tested in the study of these problems.

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## FOOTNOTES AND REFERENCES

† Leave of absence from Instituto Politecnico Nacional and Comision Nacional de la Energia Nuclear of Mexico.

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2. V. Flores-Maldonado, Regge Pole Theory and p-n and $\bar{p}$-n Charge-Exchange Scattering at Small Angles, Lawrence Radiation Laboratory Report UCRL-16799, April 1966 (submitted to Phys. Rev. Letters).

3. D. H. Sharp and W. G. Wagner, Phys. Rev. 131, 2226 (1963).

4. V. Flores-Maldonado, High Energy N-N Scattering from Regge Poles (to be submitted to Phys. Rev.).

5. The P intercept is taken at the Froissart limit; the P' at 0.7 from unpublished $\pi$-N calculations by J. J. G. Scanio (Lawrence Radiation Laboratory) 1966, and the $\omega$ at 0.5 from Ref. 4.

6. Charles Chiu (Lawrence Radiation Laboratory), private communication, 1966.

7. W. Rarita and V. L. Teplitz, Phys. Rev. Letters 12, 206 (1964).

8. R. J. N. Phillips and W. Rarita, Phys. Rev. 139, B1336 (1965); E. Leader and R. C. Slansky, Lawrence Radiation Laboratory Report UCRL-16597, December 1965 (unpublished).

9. At least for the Pomeranchuk trajectory, one may say that, if

$$\mathrm{Im}\,\alpha(s) > 0 \quad \text{and} \quad \alpha(s) = \alpha(\infty) + \frac{1}{\pi}\int_{s_0}^{s_1} \frac{ds'\,\mathrm{Im}\,\alpha(s')}{s - s'} \,,$$

then for $s < 0$, $\alpha'(s)$ is positive.

## FIGURE CAPTIONS

Fig. 1. The $g_{11}(t)$ residue functions for P, P', and $\omega$ , as a function of the invariant moment transfer $t$.

Fig. 2. The $g_{22}(t)$ residue functions for P, P', and $\omega$ , as a function of the invariant moment transfer $t$ .

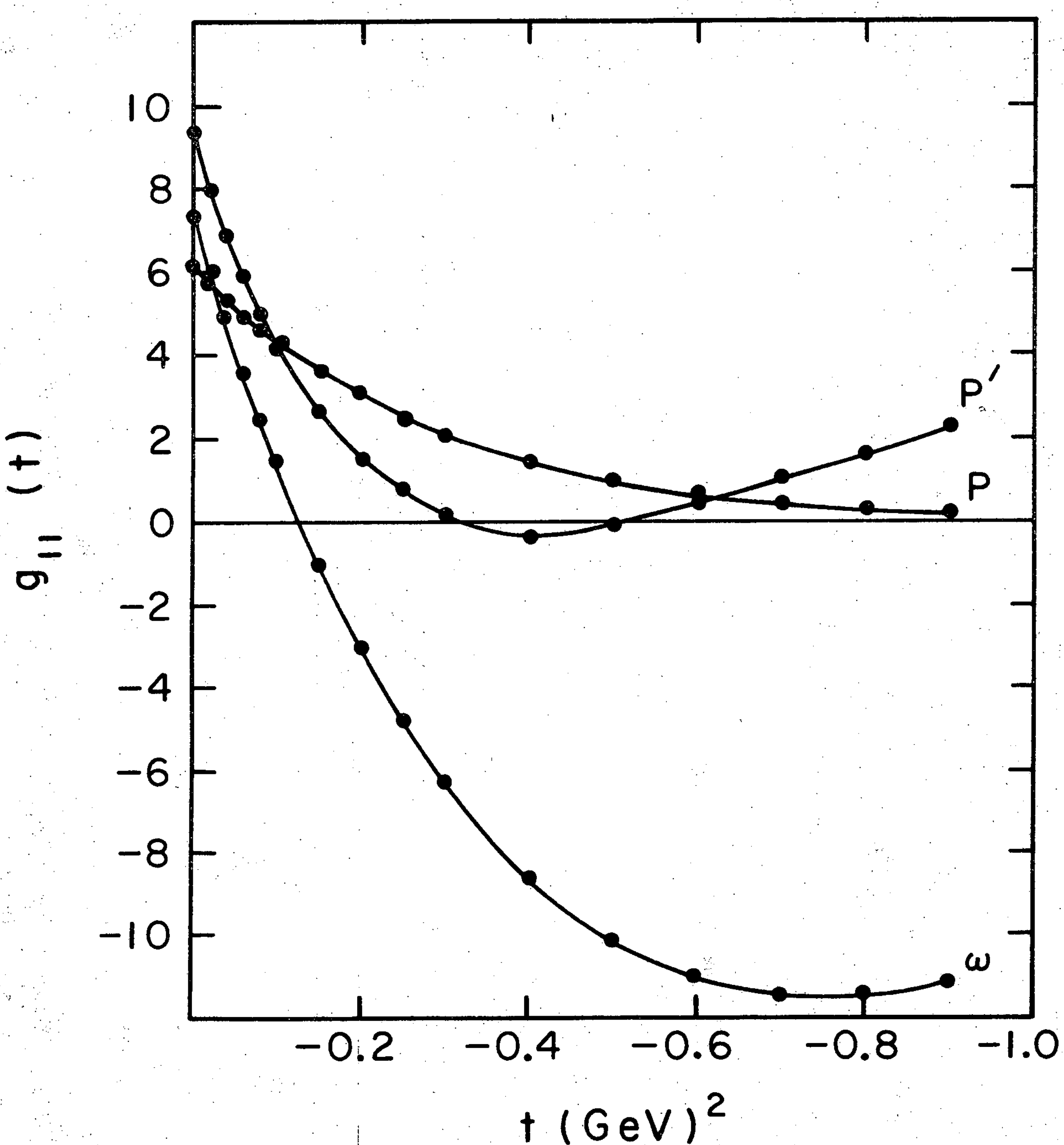


Fig. 1

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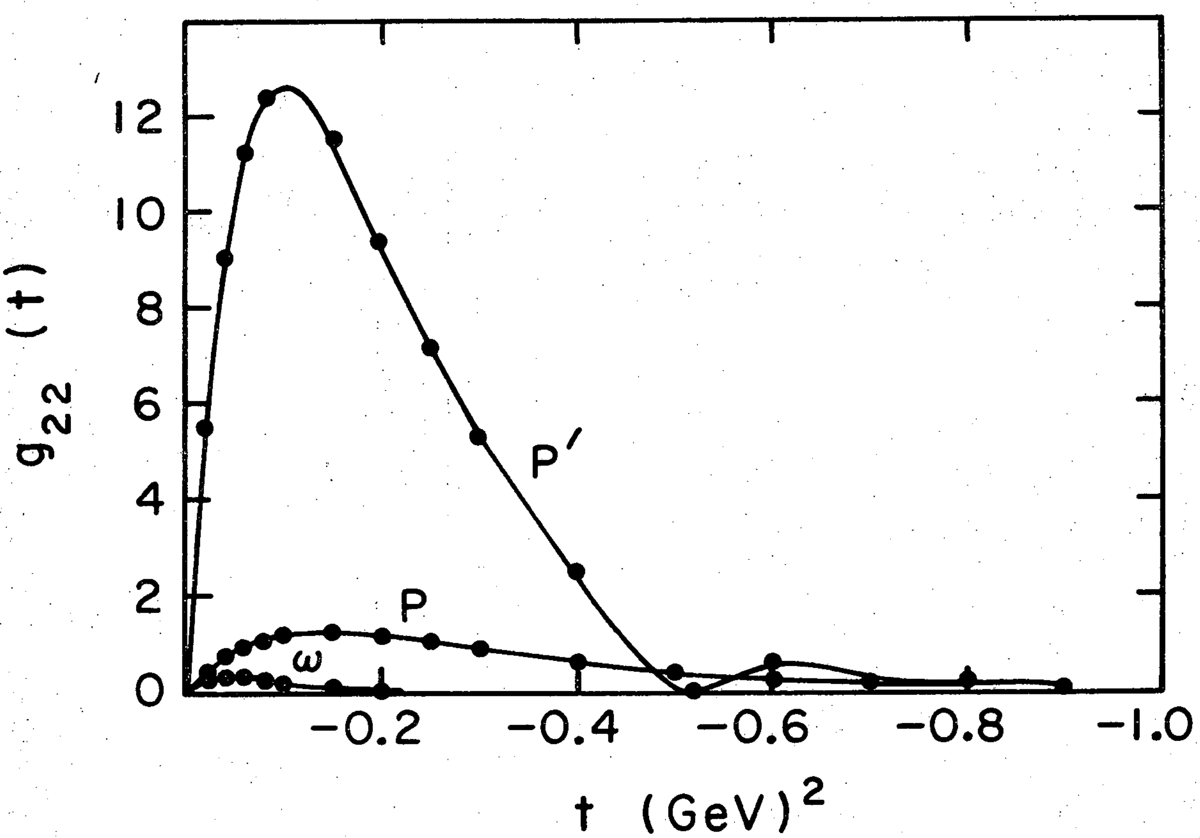


Fig. 2

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